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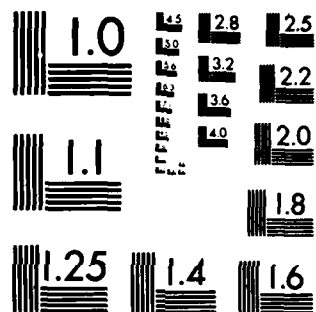
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PROSPECTS FOR OPTICAL PROBING OF THE RAYLEIGH-TAYLOR INSTABILITY IN ABLATIVELY-ACCELERATED FOIL TARGETS

I. INTRODUCTION

One of the major problems in inertial-confinement fusion (ICF) is that of understanding and avoiding the deterioration of target performance by the Rayleigh-Taylor (R-T) instability. An approach being used at the Naval Research Laboratory (NRL) is to accelerate and diagnose foil targets¹ which are designed to provide known initial conditions for the growth of the R-T instability. The behavior of these seeded or structured targets is now being predicted by numerical simulation.² In these experiments, the targets are accelerated with the NRL, Pharos II Nd-laser (1.054 micron). The first such experiments¹ used targets with a periodic rippled or step variation impressed on them. The resulting nonuniformities in the accelerated targets were diagnosed by the double-foil technique. More recently, x-ray diagnostics, including face-on backlighting and tracer dot techniques have been applied for structured targets.^{3,4} The use of x rays has the clear advantage of providing information about a high-density (near-solid) region of the accelerated target. However, one can also utilize the properties of a probing laser beam (e.g., phase, polarization, and angular scatter) to give a sensitive characterization of the structure with which the probe radiation interacts. The x-ray, double-foil and optical diagnostics are complementary in that the x-ray and double-foil methods sample high densities but are presently not able to measure perturbation wavelengths less than around 20 microns: on the other hand, the optical methods work best for the short-wavelength structure but at lower densities.

An initial optical-probing study of accelerated, R-T structured targets is discussed here. This study was first described in an oral presentation at the 1982 annual meeting of the Plasma Physics Division of the American Physical Society in New Orleans.⁵ Two diagnostic methods were used to provide simultaneous information about the rear-side and front-side (facing laser) structures in the ablatively-accelerated target. Side-on dark-field shadowgraphy was able to spatially resolve the periodic structure in the cold, accelerated rear-side target material. On the relatively-hot laser (front) side, where absorption of the laser probe beams is lower, the probing was done at a steep angle (45 degrees) with respect to the target surface. This allowed the probing radiation to penetrate into a rather dense region of the front side and provided, through the angular distribution of the scattered light intensity, evidence for periodic structure in that region.

It is useful, for both the dark-field and angular-scatter studies, to note that the light field at the back-focal plane of a lens is the spatial Fourier transform of the light field at the front focal plane.⁶ This back-focal plane is thus referred to as the Fourier-transform plane, or FTP. Since the longer wavelength components are located near the axis, or center of the FTP one can use an on-axis, opaque mask in the FTP to filter out these longer wavelengths and thus observe the more interesting steep-gradient (large wavenumber) structure. This method is used in the dark-field method. The FTP light pattern can also be characterized as an angular mapping of light rays in the front-focal plane (or target) region. This is seen intuitively since all of the rays leaving the target region in a particular direction are focused to the same point in the back-focal plane. Thus the angular distribution of scattered light can be obtained by photographically recording the FTP light pattern.

II. DARK-FIELD PROBING OF THE REAR SIDE

The dark-field probing technique has been discussed in detail in an earlier work.⁷ The experimental arrangement is illustrated in Fig. 1. A probing laser pulse is shown incident parallel to the target surface. The part of the probe radiation which passes through the large, low-density plasma is focused by the first lens and blocked by an opaque mask in the back-focal plane or FTP. Thus, a dark back-ground is produced on the film. However, the part of the probe radiation which passes through the small, steep-gradient region is strongly scattered and then collimated by the first lens to get past the mask. This radiation is then focused onto the film by the second lens to provide a bright image of the desired, steep-gradient region on the dark background. A rather large (5 mm diameter) mask was used in order to accentuate information about the steep-gradient, high-density region.

The dark-field technique is first illustrated for a uniform target. A side-on, dark-field shadowgram of a uniform 11 micron thick plastic (CH) target, accelerated with an energetic (270 J in 3 nsec) laser pulse is shown in Fig. 2. Here, the focal diameter was about 1 mm ($I = .9 \times 10^{13}$ W/cm²) and the cold target material (shown accelerated upward) was photographed 2.5 nsec after the peak of the main laser pulse. The probe was a Raman-shifted, second-harmonic of the Nd-laser pulse, with a wavelength of 6258 Å and a pulse width (FWHM) of 100 psec. Note the turbulent appearance of the accelerated plasma. This structure may have originated from a hydrodynamic instability at an earlier time. Early-time (peak of main laser pulse), dark-field structure was not observed for these uniform targets. However, interesting structure was observed at this time for the R-T structured target which is described next.

A structured 5.7 micron thick carbon foil target is shown in Fig. 3. The target was 3 mm wide, 5.7 microns thick and had a periodic thickness variation with a thick-to-thin ratio of 1.26. The basic period was 50 microns but there was also an accidental paired grouping with a period of 100 microns. The target was irradiated on the perturbed face with 260 J in 4 nsec, focused to a 1 mm spot. The shot was diagnosed at the peak of the main laser pulse by simultaneously probing with second (front side) and third (rear side) harmonic probing. These beams had a duration (FWHM) of 300 psec.

A side-on, dark-field shadowgram of such an accelerated target is shown in Fig. 4. This was taken with the third harmonic (3513 Å) probe at the peak of the main laser pulse. Again, the target is shown accelerated upward and there is a large region of emitted light from the front (lower) side. This time-integrated emitted light shows a transverse variation with a period of 50 microns. The dark-field shadowgram of the accelerated, cold target material is the rather faint pattern at the top. It shows that a 50-micron-period structure exists in the accelerated target material. The filamentary appearance can be explained by motional smearing associated with the 300 psec pulse width. Although side-on optical probing can resolve density structures in the accelerated target material, refraction and absorption would limit it, for the large target width, to densities below 10^{21} cm⁻³.

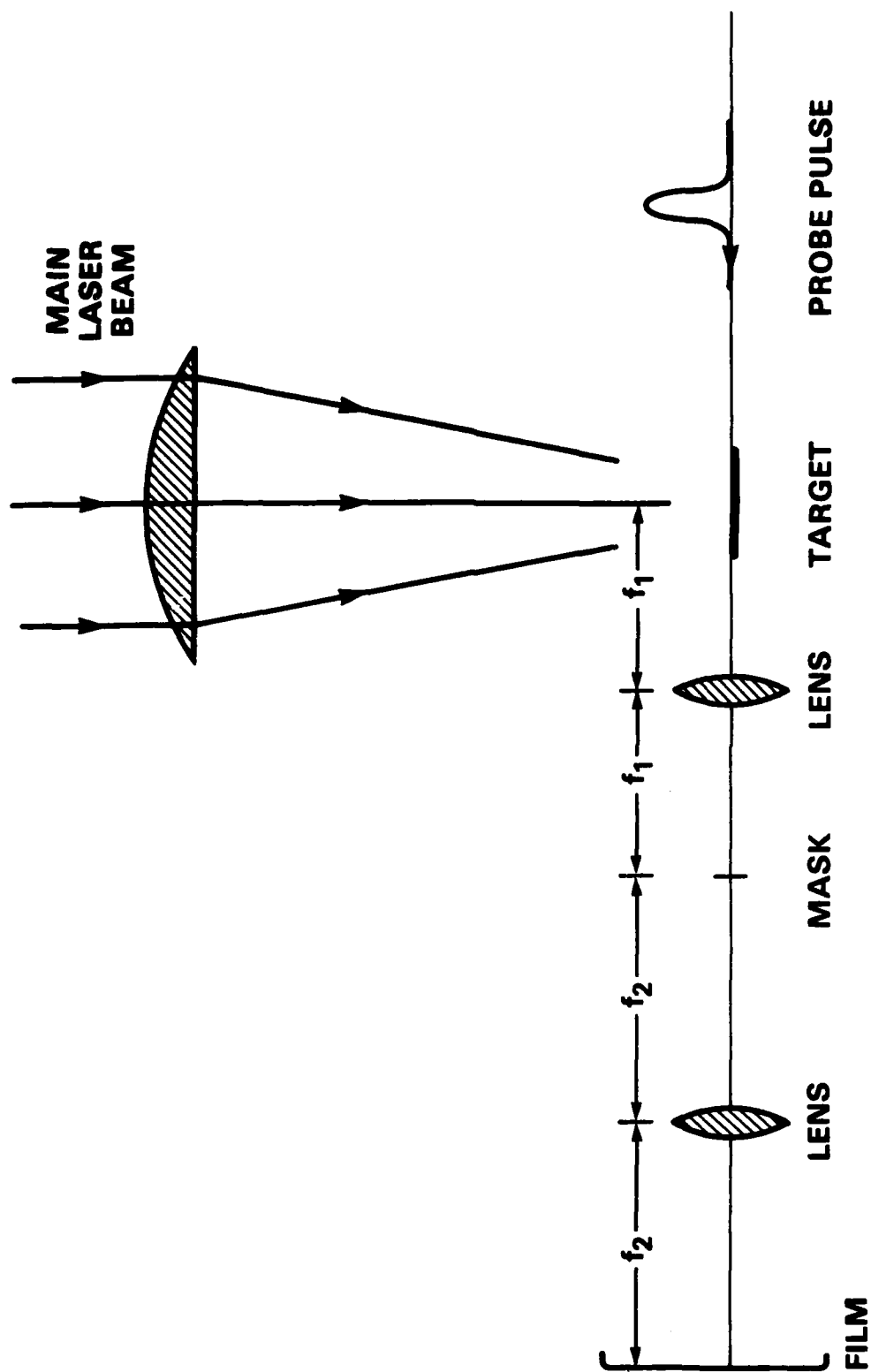
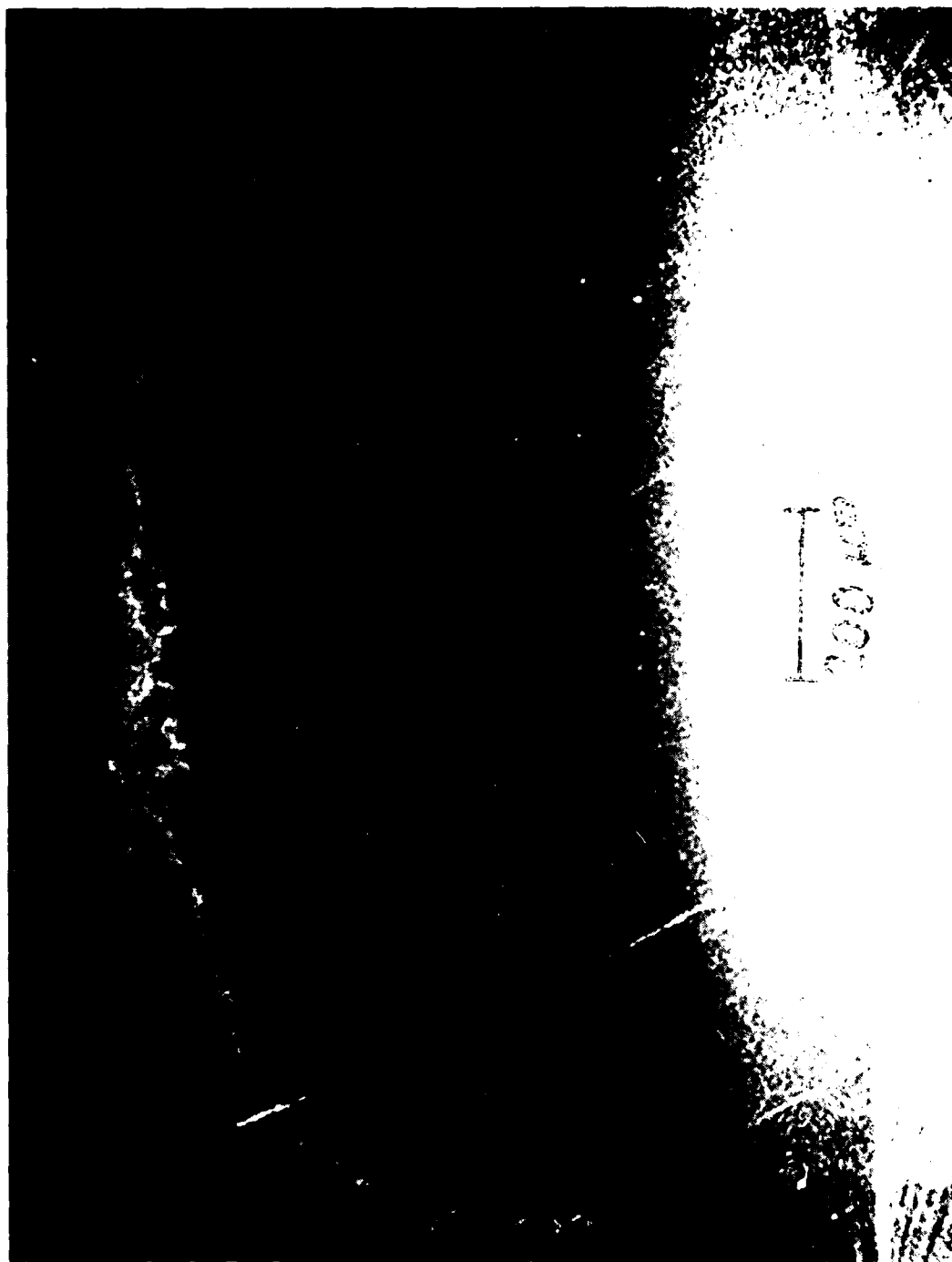
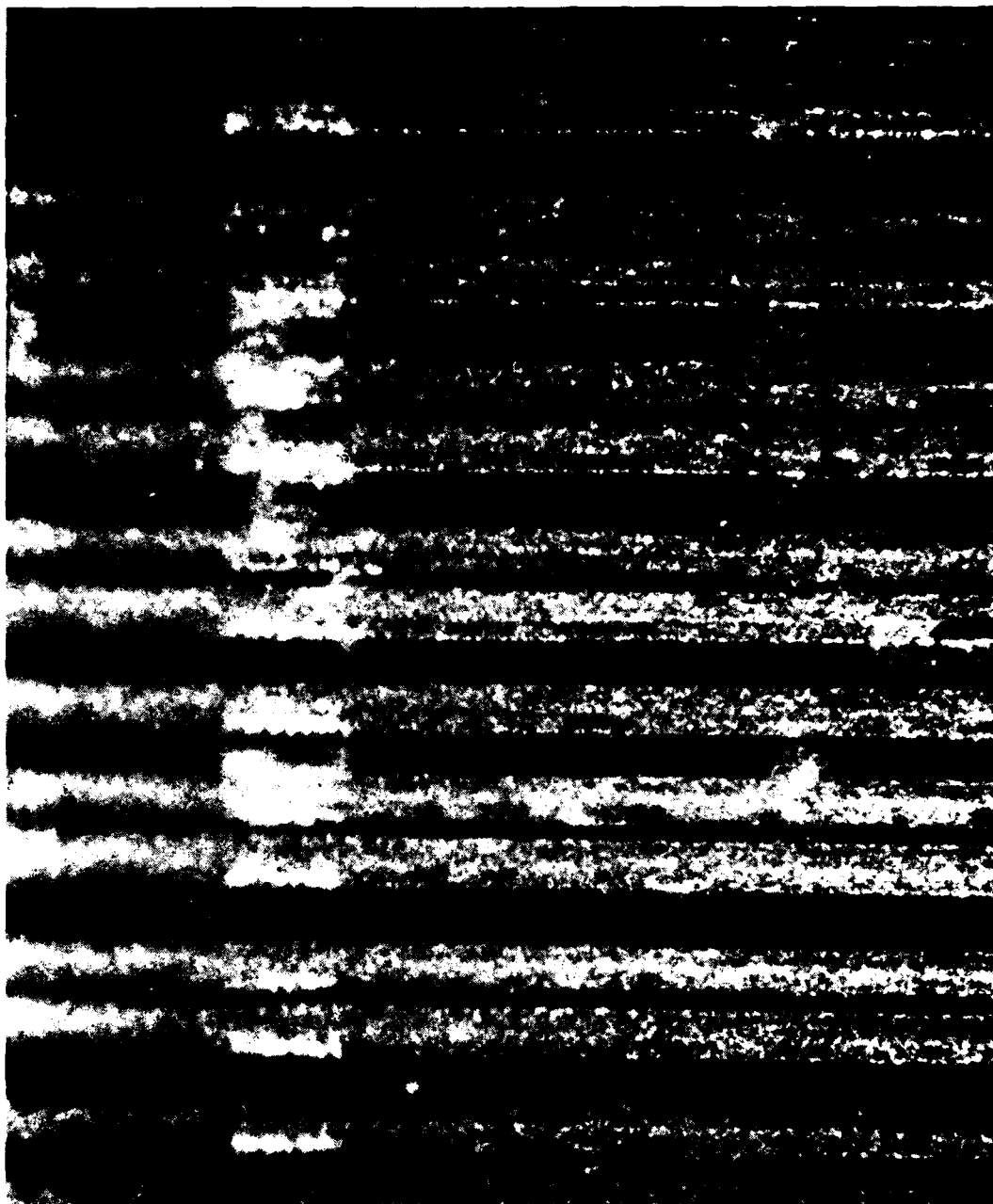


Fig. 1 — Experimental arrangement for dark-field probing.



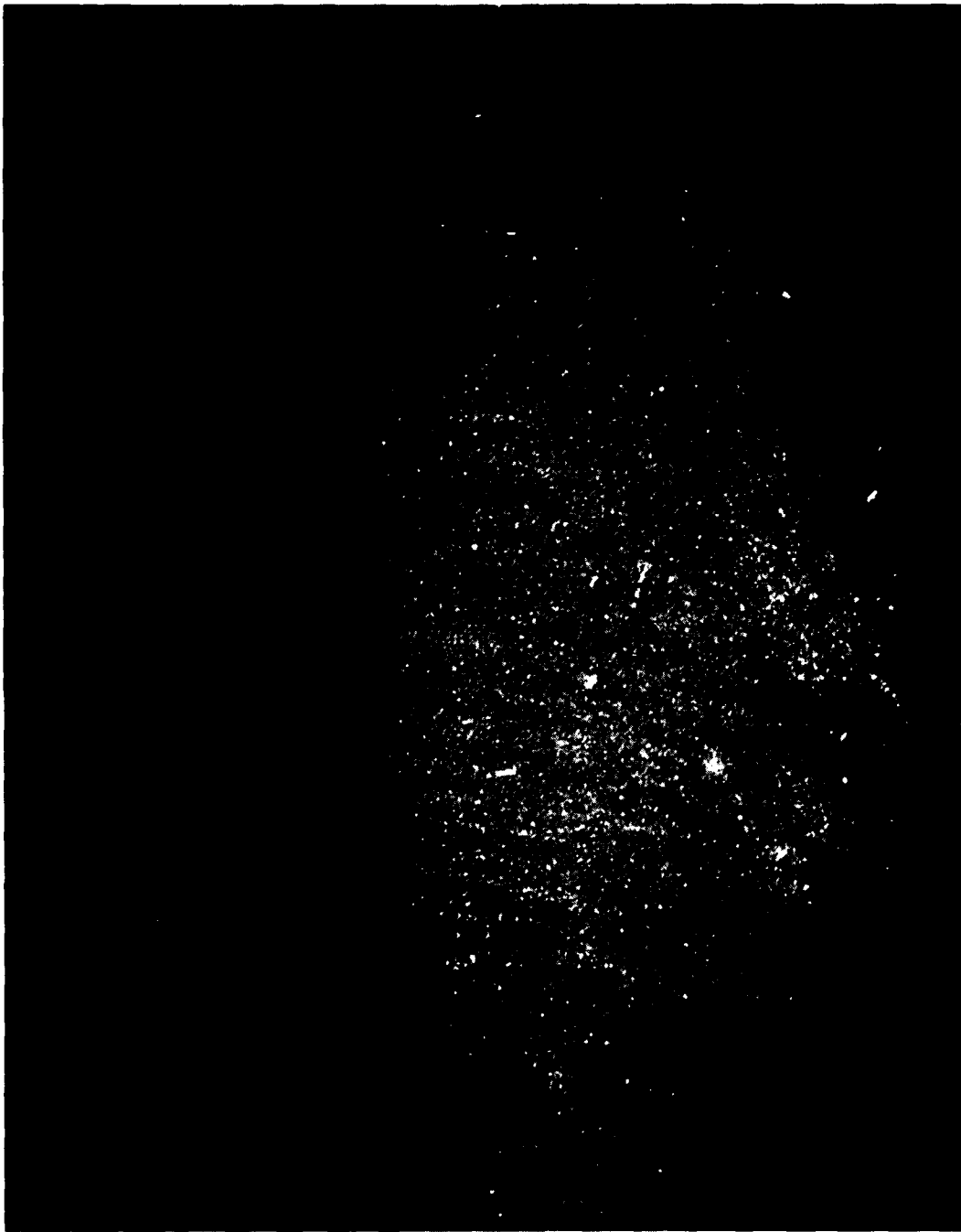
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Fig. 2 — Dark-field shadowgram of accelerated, uniform target.



R-840

Fig. 3 — Carbon target, designed to produce known initial conditions for the R-T instability.



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Fig. 4 — Dark-field shadowgram of accelerated, R-T target.

III. ANGULAR-SCATTER PROBING OF THE FRONT SIDE

On the relatively hot front side, where one is not so limited by absorption as on the rear side, one can sample densities close to 10^{22} cm^{-3} by probing at a steep angle with respect to the target surface. The experimental arrangement for obtaining the angular distribution of scattered probe light intensity from the front side of an ablatively accelerated target is shown in Fig. 5. A similar experiment was attempted on the rear side⁸ but was unsuccessful, probably because of absorption in the cold, rear-side plasma. In the present experiment, the second harmonic (5270 Å) probe beam was incident at an angle of 30 degrees with respect to the target normal. Thus, densities up to $3 \times 10^{21} \text{ cm}^{-3}$ were sampled. Had the third harmonic probe been used at 30 degrees, densities up to nearly $7 \times 10^{21} \text{ cm}^{-3}$ would have been sampled. The method illustrated here (photographing the FTP light pattern) allows one to photographically record the entire angular distribution of scattered light which is collected by a lens. It is inconvenient to directly record the light pattern at the Fourier transform plane of the first lens since this lens is rather fast - an f/2 lens with a 10 cm focal length. Thus, a second lens, with a 50 cm focal length, is used to relay the FTP light pattern, one-to-one onto the film.

A knowledge of the angular distribution of scattered light intensity provides important information about the density structures responsible for the scattering. Even an approximate knowledge of the angular distribution allows one to evaluate gross features such as shape, size and orientation. Such information can be important since steep-angle probing allows one to go to high densities but usually does not allow direct imaging. For the special case of scattering by a periodic structure, the scattered light is concentrated in those directions which are consistent with diffraction requirements (e.g., the grating equation). Thus a localization of the scattered light can be a signature of a periodic structure. However, specular reflection from a rather flat surface also provides a localized pattern and must be considered.

Useful information for a probing diagnostic is obtained by probing the target before it has been irradiated by the main laser beam. By comparing these pre-shots with the data shots one can rule out contributions from the unirradiated portions of the target and obtain a position reference. Pre-shots of the FTP light pattern due to angular scatter are often rather complicated, with contributions due to specular reflections, localized structures, and even laser coherency effects such as speckle. The pre-shot photograph of probe light scatter off of the structured carbon target is shown in Fig. 6. There is a rather pronounced speckle pattern, due to granularity in the carbon, and a general horizontal smearing consistent with the applied vertical structure. There is also a couple of intense, localized regions. Since there is a high degree of localization in both directions and the target is very flat, these intense patterns are probably due to specular reflections.

The light patterns resulting from angular scatter off of the accelerated targets were simpler than for the stationary target pre-shots. Evidently, the plasma has smoothed out many of the sources of complicated scattering. The FTP light pattern from an accelerated carbon target is shown in Fig. 7. The extremely narrow light regions are due to scratches on the film and should be ignored. Since the 3 mm target width is greater than the 1 mm focal diameter

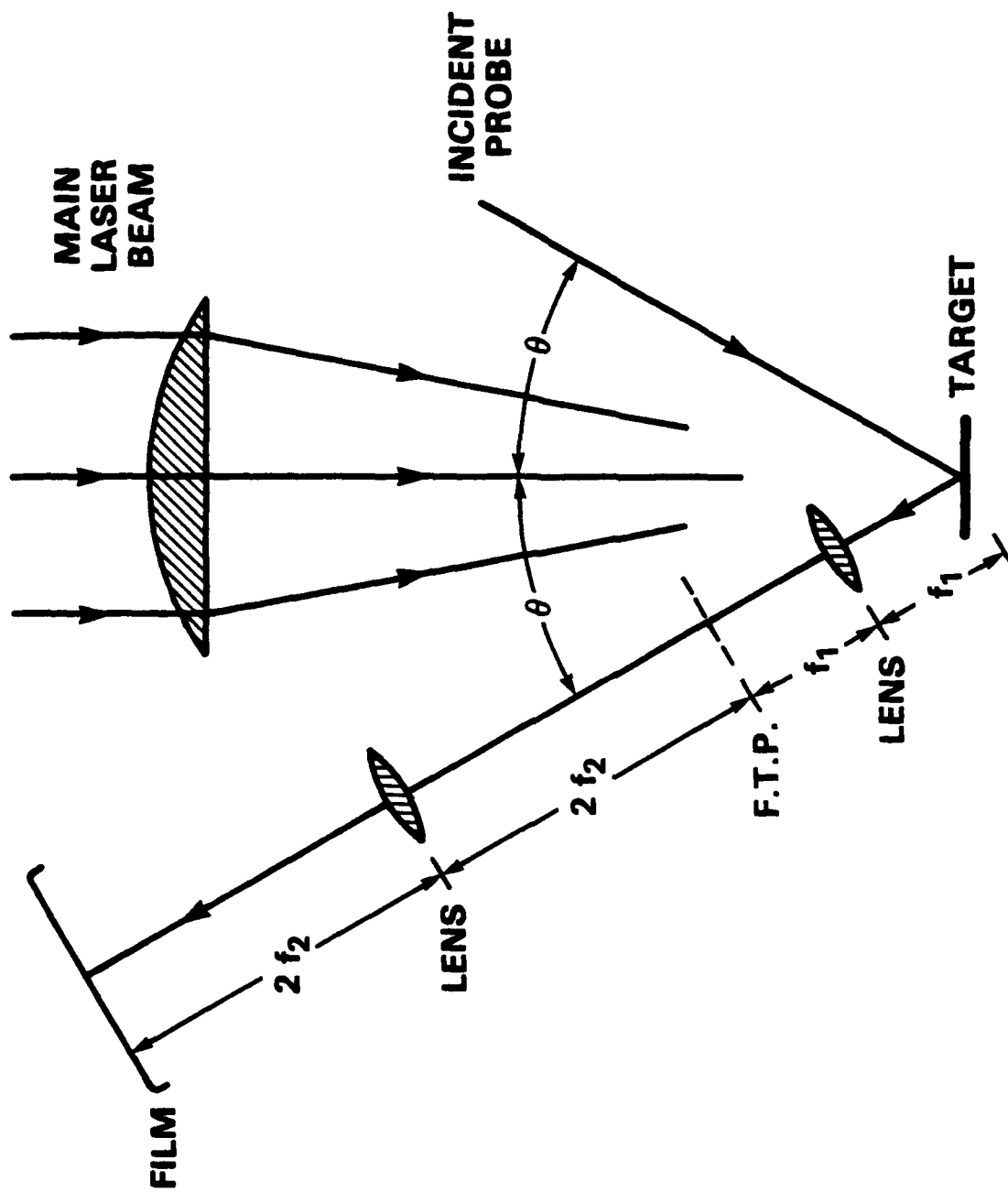
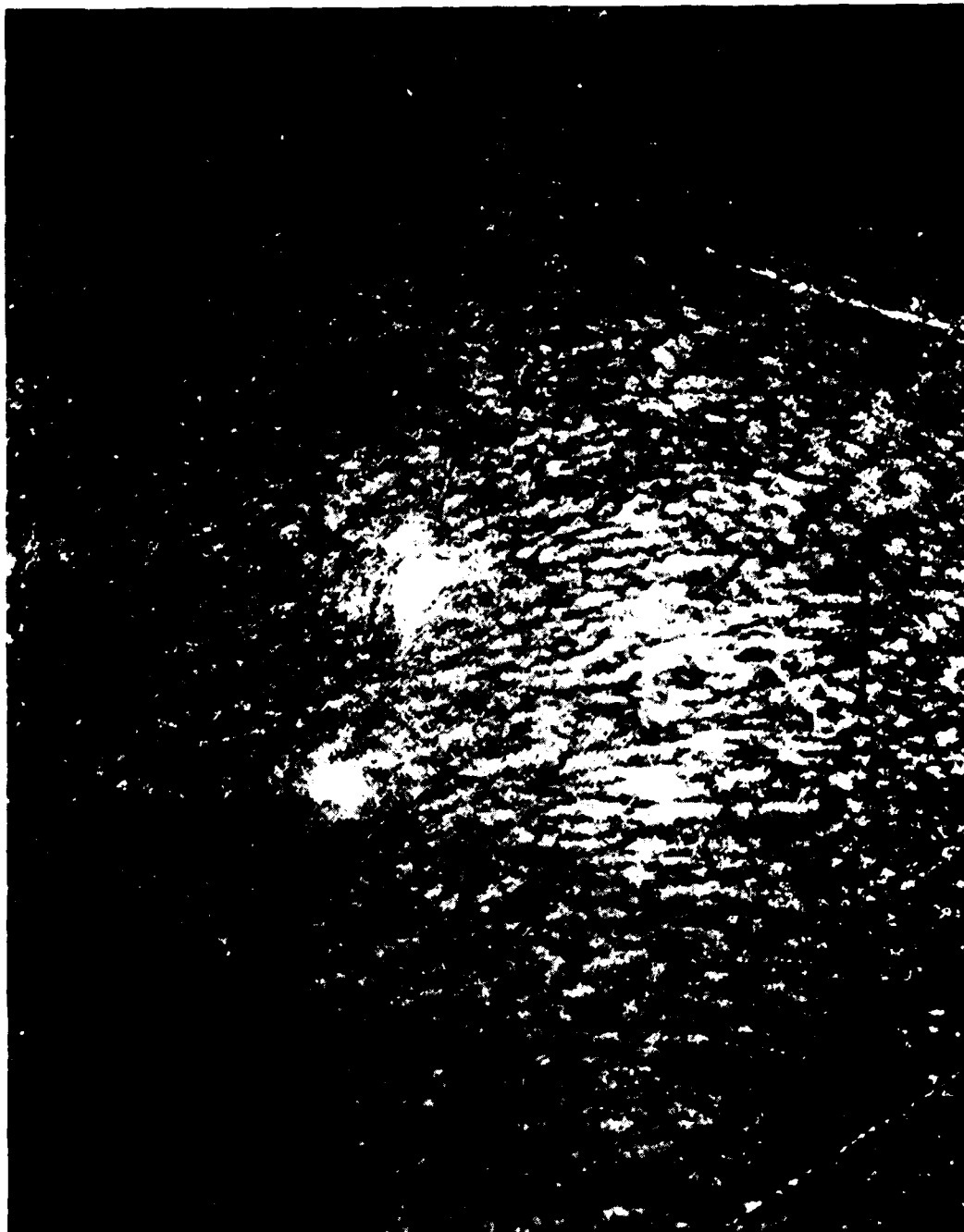


Fig. 5 — Experimental arrangement for obtaining the angular scatter of probing radiation.



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Fig. 6 — Pre-shot for angular scatter study.



R-842

Fig. 7 — Data shot for angular scatter study.

of the main laser beam, one must consider scattering from outside the more intense part of the main beam focus. Such scattering could occur from regions close enough to the focus that a plasma exists or from the larger region having no plasma. Scattering from the region with no plasma should be nearly the same as for the pre-shot. This contribution seems to be unimportant since the light pattern in the data shot differs greatly from that in the pre-shot. Light scatter from the plasma region outside of the focal spot is also unlikely to be important since, at an angle of incidence of 30 degrees, plasma absorption is nearly complete for temperatures much below 200 eV.

It is interesting that the horizontal angular width of the intense region agrees rather well with what one would expect for the diffraction pattern from a simple periodic structure with a perturbation wavelength of 50 microns. This is not seen in the initial target preshot. Evidently, the initial target produces so much complicated scattering (due to specular reflections, localized structures and coherency effects) that the periodicity of the applied structure is not a dominant effect. However, a simple periodic structure in the accelerated target plasma would produce the observed intense pattern and angular width. The expected width is the ratio of the .5 micron probe wavelength to the 50 micron perturbation wavelength, i.e., 10 mrad, as observed. The narrower angular spread in the other direction (vertical) is probably specular since, at early times, the accelerated target is still rather flat parallel to the perturbations. There is also a set of rather faint, vertically-repeated patterns. These are probably caused by interference due to reflections off a filter in front of the recording camera. Thus, although complicated in detail, the observed angular scatter off of the accelerated target is consistent with a simple, periodic plasma structure.

IV. CONCLUSION

Density nonuniformities have been optically resolved in structured targets which were ablatively accelerated. These results show that optical probing is promising for diagnosing the Rayleigh-Taylor instability. A study was carried out on a carbon target designed to provide known initial conditions for the growth of the instability. Two optical diagnostic techniques were used simultaneously. A side-on, dark-field shadowgram (third harmonic) showed periodic structure in a steep-gradient region on the rear side of the accelerating target. The angular scatter pattern for steep-angle probing (second harmonic) of the front side of the target was shown to be consistent with the expected (imposed) periodic structure in the accelerated target. Steep-angle probing has the advantage of being sensitive to short-wavelength nonuniformities at moderate plasma densities. Additional steep-angle probing diagnostics are envisioned. For example, one could determine the density gradient scalelength by measuring the polarization state of the scattered light.¹⁰

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